

## Claims

We claim:

1. A computer-implemented method for performing edge detection in an  
5 image comprising a plurality of pixels, the method comprising:
  - a) receiving the plurality of pixels;
  - b) generating a curve based on two or more random pixels of the plurality of  
pixels;
  - c) testing the curve against a first subset of the plurality of pixels, wherein said  
10 testing produces first test results;
  - d) if said first test results meet first criteria, outputting information regarding the  
curve, wherein the curve comprises a detected edge in the image.
2. The method of claim 1, wherein the method comprises performing (b) and  
15 (c) a plurality of times to determine a curve which meets the first criteria.
3. The method of claim 2, wherein said performing (b) and (c) a plurality of  
times comprises performing (b) and (c) in an iterative manner until ending criteria are  
met.  
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4. The method of claim 3, wherein said ending criteria comprise one or more  
of:
  - the number of iterations meeting or exceeding an iteration threshold; and
  - a number of pixels of the plurality of pixels within a specified pixel radius of the  
25 curve meeting or exceeding a specified minimum value.
5. The method of claim 1, further comprising:
  - pre-testing the curve against a second subset of the plurality of pixels, wherein  
said testing produces second test results;

wherein, if said second test results meet second criteria, then performing c) and d).

6. The method of claim 5, wherein the second subset is smaller than the first subset.

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7. The method of claim 5, wherein the second subset is a random subset comprising randomly selected pixels from the plurality of pixels.

8. The method of claim 7, further comprising:  
10 randomizing the plurality of pixels after said receiving to generate a randomized list of the plurality of pixels;

wherein said randomly selected pixels from the plurality of pixels are selected by traversing the randomized list.

9. The method of claim 8, wherein said randomizing the plurality of pixels  
15 further comprises selecting a random starting position in the randomized list, and wherein said traversing the randomized list comprises traversing the randomized list starting at the random starting position.

10. The method of claim 5, wherein said pre-testing the curve against a second  
20 subset of the plurality of pixels comprises:

determining a number of the second subset of the plurality of pixels which are within the specified pixel radius of the curve;

25 wherein said second test results comprise said number of the second subset of the plurality of pixels which are within the specified pixel radius of the curve.

11. The method of claim 10, wherein said second criteria comprise said number of the second subset of the plurality of pixels which are within the specified pixel radius of the curve meeting or exceeding a threshold value.



pixels from the second subset, generating a culled subset of pixels, and fitting a refined curve to the culled subset at each iteration until an ending condition is met, wherein the refined curve fit generates a refined curve, and

generating output, comprising one or more of information regarding the refined curve, and the culled subset of the plurality of pixels.

19. The method of claim 18, wherein said performing a refined curve fit comprises:

calculating a maximum error allowed for the refined curve fit based on the specified pixel radius;

removing one or more pixels from the second subset, wherein said one or more pixels are furthest from curve, thereby generating a culled subset;

fitting a curve to the culled subset;

calculating an error for the curve on the culled subset;

repeating said removing, said fitting, and said calculating one or more times to generate a refined curve; and

generating result output, wherein said result output comprises one or more of:

the culled subset;

the refined curve, wherein the refined curve comprises a refined detected edge in the image;

the error for the curve on the culled subset;

a score, indicating the fitness of the refined curve with respect to the plurality of pixels; and

the plurality of pixels.

20. The method of claim 1, wherein the image has a dimensionality greater than two.

21. A computer-implemented method for detecting an edge in an image comprising a plurality of pixels, the method comprising:

a) receiving the plurality of pixels;

b) performing the following steps c) through f) in an iterative manner:

5 c) generating a curve based on two or more random pixels of the plurality of pixels;

d) pre-testing the curve against a first random subset of the plurality of pixels, wherein said testing produces first test results;

10 e) if said first test results meet first criteria, testing the curve against a second subset of the plurality of pixels, thereby generating second test results;

f) if said second test results meet second criteria, storing information regarding the curve; and

g) outputting said information regarding the curve, wherein the curve comprises a detected edge in the image.

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22. The method of claim 21, further comprising:

randomizing the order of the plurality of pixels before said performing to produce a randomized list of the plurality of pixels;

wherein said first random subset is selected by traversing said randomized list.

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23. The method of claim 22, wherein said randomizing the plurality of pixels further comprises selecting a random starting position in the randomized list, and wherein said traversing the randomized list comprises traversing the randomized list from the random starting position.

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24. The method of claim 21, wherein second subset substantially comprises pixels which are not in said first subset.

25. The method of claim 21, wherein said performing the steps c) through f) in an iterative manner comprises performing the steps c) through f) in an iterative manner until third criteria are met.

5 26. The method of claim 25, wherein said third criteria comprise one or more of:

the number of iterations meeting or exceeding an iteration threshold; and

a number of pixels of the plurality of pixels within a specified pixel radius of the curve meeting or exceeding a specified minimum value.

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27. The method of claim 21, wherein the first subset is smaller than the second subset.

15 28. The method of claim 21, wherein said pre-testing the curve against a first subset of the plurality of pixels comprises:

determining a number of the first subset of the plurality of pixels which are within a specified pixel radius of the curve;

wherein said first test results comprise said number of the first subset of the plurality of pixels which are within the specified pixel radius of the curve.

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29. The method of claim 28, wherein said first criteria comprise said number of the first subset of the plurality of pixels which are within the specified pixel radius of the curve meeting or exceeding a threshold value.

25 30. The method of claim 28, wherein said first criteria comprise said number of the first subset of the plurality of pixels which are within the specified pixel radius of the curve meeting or exceeding a specified fraction of the first subset.

31. The method of claim 28, wherein said testing the curve against the second subset of the plurality of pixels comprises:

determining a number of the second subset of the plurality of pixels which are within a specified pixel radius of the curve;

5 wherein said second test results comprise said number of the second subset of the plurality of pixels which are within the specified pixel radius of the curve.

32. The method of claim 31, wherein said second criteria comprise said number of the second subset of the plurality of pixels which are within the specified pixel  
10 radius of the curve meeting or exceeding a specified fraction of the second subset.

33. The method of claim 31, wherein said second criteria comprise said number of the second subset of the plurality of pixels which are within the specified pixel radius of the curve plus said number of the first subset of the plurality of pixels which are  
15 within the specified pixel radius of the curve meeting or exceeding a specified fraction of the plurality of pixels.

34. The method of claim 21, wherein said outputting information comprises displaying the detected edge on a display device.  
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35. The method of claim 21, wherein information regarding the curve comprises one or more of:

one or more parameters defining the curve;

a third subset of the plurality of pixels, comprising pixels which are within a  
25 specified pixel radius of the curve.

36. The method of claim 21, wherein the curve comprises one of a line, a circle, and an ellipse.

37. The method of claim 21, wherein the image has a dimensionality greater than two.

38. The method of claim 21, further comprising:

5 performing a refined curve fit, wherein the refined curve fit is performed using a third subset of the plurality of pixels comprising pixels within a specified pixel radius of the curve, wherein performing the refined curve fit comprises iteratively culling outlying pixels from the third subset, generating a culled subset of pixels, and fitting a refined curve to the culled subset at each iteration until an ending condition is met, thereby  
10 generating a refined curve, and  
generating output, comprising one or more of information regarding the generated refined curve, and the culled subset of the plurality of pixels, wherein the generated refined curve comprises a refined detected edge in the image.

15 39. The method of claim 38, wherein said performing a refined curve fit comprises:

calculating a maximum error allowed for the refined curve fit based on the specified pixel radius;  
fitting a curve to the third subset of pixels;  
20 removing one or more pixels from the third subset, wherein said one or more pixels are furthest from the curve, thereby generating a culled subset;  
fitting a curve to the culled subset;  
calculating an error for the curve on the culled subset;  
repeating said removing, said fitting, and said calculating one or more times to  
25 generate a refined curve; and  
generating result output, wherein said result output comprises one or more of:  
the culled subset;  
the generated refined curve, wherein the generated refined curve comprises a refined detected edge in the image;



the calculated error for the curve on the culled subset;  
a score, indicating the fitness of the refined curve with respect to the plurality of pixels; and  
the plurality of pixels.

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40. A computer-implemented method for detecting an edge in an image comprising a plurality of pixels, the method comprising:

- a) receiving the plurality of pixels, P;
  - b) randomizing the order of the plurality of pixels P;
  - 10 c) performing the following steps d) through j) in an iterative manner:
    - d) selecting two or more pixels from P;
    - e) generating a curve using the two or more pixels, wherein said generating comprises calculating two or more parameters defining the curve;
    - f) selecting a subset  $P_m$  of P, wherein  $P_m$  comprises M pixels;
    - 15 g) determining and recording a subset  $P_j$  of  $P_m$ , wherein  $P_j$  comprises J pixels in  $P_m$  whose distance from the curve is less than or equal to a specified pixel radius.
    - h) if a ratio of J to M exceeds a threshold, updating the recorded subset  $P_j$  and J to include all pixels in P whose distance from the curve is less than or equal
    - 20 to the specified pixel radius;
    - i) if J exceeds all values of J calculated in previous iterations, recording the subset  $P_j$  as a subset  $P_{max}$ , comprising  $J_{max}$  pixels, and recording the two or more parameters defining the curve, wherein the curve comprises an estimated fit to the plurality of pixels, P;
    - 25 j) testing for criteria to end said iterating; and
    - k) generating output, wherein said output comprises the subset  $P_{max}$ , and said two or more parameters defining the generated curve;
- wherein said criteria comprise one or more of:
- the number of iterations meeting or exceeding an iteration threshold; and

the value of  $J_{\max}$  meeting or exceeding a minimum pixel count; and  
wherein the generated curve comprises a detected edge in the image.

41. The method of claim 40, wherein said at least two pixels comprise  $N_c$   
5 pixels, and wherein said performing a refined curve fit comprises:

l) calculating a maximum error  $\text{err}_{\max}$  allowed for the refined curve fit based on the  
specified pixel radius;

m) setting an optimal set of pixels  $K_0$  to  $P_{\max}$ ;

n) fitting an initial curve  $L_0$  to the optimal set of pixels  $K_0$ ;

10 o) calculating an error  $\text{err}_0$  for the initial curve  $L_0$  on  $K_0$ ;

p) determining if an ending condition is true;

q) if said ending condition is not true, performing the following steps r) through u)  
iteratively, until said ending condition is true, wherein  $K_i$  is a state of the set  $K_0$  at each  
iteration  $i$ , and  $L_i$  is a corresponding line fitted to  $K_i$ ;

15 r) removing  $P_i$  pixels from  $K_i$ , wherein said  $P_i$  pixels are furthest from  
curve  $L_i$ , thereby generating subset  $K_{i+1}$  of  $K_i$ ;

s) fitting a curve  $L_{i+1}$  to subset  $K_{i+1}$ ;

t) calculating an error  $\text{err}_{i+1}$  for the curve  $L_{i+1}$  on subset  $K_{i+1}$ ;

u) incrementing  $i$ ;

20 wherein said ending condition comprises one or more of:

$\text{err}_i$  meeting or exceeding  $\text{err}_{\max}$ ; and

a count of  $K_i$  being equal to  $N_c$ ;

v) calculating a score  $s_{\text{final}}$  of a final curve  $L_{\text{final}}$  on a final subset  $K_{\text{final}}$ , wherein  $L_{\text{final}}$   
and subset  $K_{\text{final}}$  comprise final states of  $L_i$  and  $K_i$ , respectively; and

25 w) calculating an error  $\text{err}_{\text{final}}$  of the curve  $L_{\text{final}}$  on the plurality of pixels  $P$ ;

x) generating result output, wherein said result output comprises one or more of:

the final subset  $K_{\text{final}}$ ;

the size of  $K_{\text{final}}$ ;

the curve  $L_{\text{final}}$ , comprising a refined detected edge in the image;

the score  $s_{final}$ ; and  
the plurality of pixels P.

42. A memory medium operable to store program instructions for performing  
5 edge detection in a received image comprising a plurality of pixels, wherein the program  
instructions are executable to perform:

a) generating a curve based on two or more random pixels of the plurality of  
pixels;

b) testing the curve against a first subset of the plurality of pixels, wherein said  
10 testing produces first test results;

c) if said first test results meet first criteria, outputting information regarding the  
curve, wherein the curve comprises a detected edge in the image.

43. The memory medium of claim 42, wherein the program instructions are  
15 further executable to perform (a) and (b) a plurality of times to determine a curve which  
meets the first criteria.

44. The memory medium of claim 42, wherein the program instructions are  
further executable to perform:

20 pre-testing the curve against a second subset of the plurality of pixels, wherein  
said testing produces second test results, wherein said second subset is a random subset  
comprising randomly selected pixels from the plurality of pixels;

wherein, if said second test results meet second criteria, then performing b) and c).

25 45. The memory medium of claim 44, wherein the program instructions are  
further executable to perform:

randomizing the plurality of pixels after said receiving to generate a randomized  
list of the plurality of pixels;

wherein said randomly selected pixels from the plurality of pixels are selected by traversing the randomized list.

46. The memory medium of claim 44,

5 wherein said pre-testing the curve against a second subset of the plurality of pixels comprises determining a number of the second subset of the plurality of pixels which are within a specified pixel radius of the curve;

wherein said second test results comprise said number of the second subset of the plurality of pixels which are within the specified pixel radius of the curve;

10 wherein said second criteria comprise said number of the second subset of the plurality of pixels which are within the specified pixel radius of the curve meeting or exceeding a threshold value;

wherein said testing the curve against a first subset of the plurality of pixels comprises determining a number of the first subset of the plurality of pixels which are  
15 within the specified pixel radius of the curve;

wherein said first test results comprise said number of the first subset of the plurality of pixels which are within the specified pixel radius of the curve; and

wherein said first criteria comprise said number of the first subset of the plurality of pixels which are within the specified pixel radius of the curve meeting or exceeding a  
20 threshold value.

47. The memory medium of claim 42, wherein the program instructions are further executable to perform:

performing a refined curve fit, wherein the refined curve fit is performed using a  
25 second subset of the plurality of pixels comprising pixels within said specified pixel radius of the curve, wherein the refined curve fit comprises iteratively culling outlying pixels from the second subset, generating a culled subset of pixels, and fitting a refined curve to the culled subset at each iteration until an ending condition is met, wherein the refined curve fit generates a refined curve, and

generating output, comprising one or more of information regarding the refined curve, and the culled subset of the plurality of pixels, wherein the curve comprises a refined detected edge in the image.

5           48.     A memory medium operable to store program instructions for performing edge detection in an image comprising a plurality of pixels, wherein the program instructions are executable to perform:

          a) performing the following steps b) through e) in an iterative manner:

          b) generating a curve based on two or more random pixels of the plurality  
10   of pixels;

          c) pre-testing the curve against a first random subset of the plurality of pixels, wherein said testing produces first test results;

          d) if said first test results meet first criteria, testing the curve against a second subset of the plurality of pixels, thereby generating second test results;

15           e) if said second test results meet second criteria, storing information regarding the curve; and

          f)     outputting said information regarding the curve, wherein the curve comprises a detected edge in the image.

20           49.     The memory medium of claim 48, wherein the program instructions are further executable to perform:

          randomizing the order of the plurality of pixels before said performing to produce a randomized list of the plurality of pixels;

          wherein said first random subset is selected by traversing said randomized list.

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          50.     The memory medium of claim 48,

          wherein said pre-testing the curve against a first subset of the plurality of pixels comprises determining a number of the first subset of the plurality of pixels which are within a specified pixel radius of the curve;



generating output, comprising one or more of information regarding the generated refined curve, and the culled subset of the plurality of pixels, wherein the curve comprises a refined detected edge in the image.

5           53.    A computer based system for performing edge detection in an image comprising a plurality of pixels, the system comprising:

          a CPU;

          a memory medium coupled to the CPU, wherein the memory is operable to store program instructions for performing edge detection, and wherein the CPU is operable to  
10   execute the program instructions; and

          an input which is operable to receive the plurality of pixels;

          wherein the program instructions are executable by the CPU to perform:

          a) generating a curve based on two or more random pixels of the plurality  
of pixels;

15           b) testing the curve against a first subset of the plurality of pixels, wherein said testing produces first test results;

          c) if said first test results meet first criteria, outputting information regarding the curve, wherein the refined curve comprises a detected edge in the image.

20           54.    The system of claim 53, wherein the program instructions are further executable by the CPU to perform (a) and (b) a plurality of times to determine a curve which meets the first criteria.

25           55.    The system of claim 53, wherein the program instructions are further executable by the CPU to perform:

          pre-testing the curve against a second subset of the plurality of pixels, wherein said testing produces second test results, wherein said second subset is a random subset comprising randomly selected pixels from the plurality of pixels;

          wherein, if said second test results meet second criteria, then performing b) and c).

56. The system of claim 55, wherein the program instructions are further executable by the CPU to perform:

randomizing the plurality of pixels after said receiving to generate a randomized  
5 list of the plurality of pixels;  
wherein said randomly selected pixels from the plurality of pixels are selected by  
traversing the randomized list.

57. The system of claim 55,  
10 wherein said pre-testing the curve against a second subset of the plurality of pixels  
comprises determining a number of the second subset of the plurality of pixels which are  
within a specified pixel radius of the curve;

wherein said second test results comprise said number of the second subset of the  
plurality of pixels which are within the specified pixel radius of the curve;  
15 wherein said second criteria comprise said number of the second subset of the  
plurality of pixels which are within the specified pixel radius of the curve meeting or  
exceeding a threshold value;

wherein said testing the curve against a first subset of the plurality of pixels  
comprises determining a number of the first subset of the plurality of pixels which are  
20 within the specified pixel radius of the curve;

wherein said first test results comprise said number of the first subset of the  
plurality of pixels which are within the specified pixel radius of the curve; and

wherein said first criteria comprise said number of the first subset of the plurality  
of pixels which are within the specified pixel radius of the curve meeting or exceeding a  
25 threshold value.

58. The system of claim 53, wherein the program instructions are further  
executable by the CPU to perform:



performing a refined curve fit, wherein the refined curve fit is performed using a second subset of the plurality of pixels comprising pixels within said specified pixel radius of the curve, wherein the refined curve fit comprises iteratively culling outlying pixels from the second subset, generating a culled subset of pixels, and fitting a refined curve to the culled subset at each iteration until an ending condition is met, wherein the refined curve fit generates a refined curve, and

generating output, comprising one or more of information regarding the refined curve, and the culled subset of the plurality of pixels, wherein the refined curve comprises a refined detected edge in the image.

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59. A computer based system for performing a curve fit, comprising:

a CPU;

a memory medium coupled to the CPU, wherein the memory is operable to store program instructions, and wherein the CPU is operable to execute the program

15 instructions; and

an input which is operable to receive a plurality of pixels;

wherein the program instructions are executable by the CPU to perform:

a) performing the following steps b) through e) in an iterative manner:

b) generating a curve based on two or more random pixels of the plurality of pixels;

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c) pre-testing the curve against a first random subset of the plurality of pixels, wherein said testing produces first test results;

d) if said first test results meet first criteria, testing the curve against a second subset of the plurality of pixels, thereby generating second test results;

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e) if said second test results meet second criteria, storing information regarding the curve; and

f) outputting said information regarding the curve, wherein the curve comprises a detected edge in the image.

60. The system of claim 59, wherein the program instructions are further executable by the CPU to perform:

randomizing the order of the plurality of pixels before said performing to produce a randomized list of the plurality of pixels;

5 wherein said first random subset is selected by traversing said randomized list.

61. The system of claim 59,

wherein said pre-testing the curve against a first subset of the plurality of pixels comprises determining a number of the first subset of the plurality of pixels which are  
10 within a specified pixel radius of the curve;

wherein said first test results comprise said number of the first subset of the plurality of pixels which are within the specified pixel radius of the curve;

wherein said first criteria comprise said number of the first subset of the plurality of pixels which are within the specified pixel radius of the curve meeting or exceeding a  
15 first threshold value;

wherein said testing the curve against the second subset of the plurality of pixels comprises determining a number of the second subset of the plurality of pixels which are within the specified pixel radius of the curve;

wherein said second test results comprise said number of the second subset of the  
20 plurality of pixels which are within the specified pixel radius of the curve; and

wherein said second criteria comprise said number of the second subset of the plurality of pixels which are within the specified pixel radius of the curve meeting or exceeding a second threshold value.

25 62. The system of claim 61, wherein said second criteria further comprise said number of the second subset of the plurality of pixels which are within the specified pixel radius of the curve plus said number of the first subset of the plurality of pixels which are within the specified pixel radius of the curve meeting or exceeding the specified second threshold value.

63. The system of claim 59, wherein the program instructions are further executable by the CPU to perform:

5 performing a refined curve fit, wherein the refined curve fit is performed using a third subset of the plurality of pixels comprising pixels within a specified pixel radius of the curve, wherein performing the refined curve fit comprises iteratively culling outlying pixels from the third subset, generating a culled subset of pixels, and fitting a refined curve to the culled subset at each iteration until an ending condition is met, thereby generating a refined curve, and

10 generating output, comprising one or more of information regarding the generated refined curve, and the culled subset of the plurality of pixels, wherein the generated refined curve comprises a refined detected edge in the image.

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